

# Forestland prediction of China based on forest ecosystem services for the first half of 21st century

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**Abstract:** A new model was developed to predict forestland demand of China during the years of 2010–2050 in terms of the concept of forest ecosystem services. On the basis of the relationship between forest ecosystem services and classified forest management, we hypothesized that the ecological-forest provides ecological services, whereas commercial-forest supplies wood and timber production, and the influences of the growth of population, social-economic development target, forest management methods and the technology changes on forest resources were also taken into account. The prediction reveals that the demand of total forestland of China will be 244.8, 261.2 and 362.2 million ha by the year 2010, 2020 and 2050, respectively. The results demonstrated that China will be confronted with a shortage of forest resources, especially with lack of ecological-oriented forests, in the future. It is suggested that sustainable management of forest resources must be reinforced and more attention should be drawn to enhancing the service function of forest ecosystem.

**Keywords:** forest resources; forest ecosystem services; forestland prediction; commercial forest; ecological forest; timber demand; ecological demand

## Introduction

As a rapidly-growing developing country, China has deficient forest resources in proportion to its growth rates of population and GDP. China's forest cover area is only 18.21% by the end of 2005, only 60% of the world average forest coverage, and the forested area only accounts for 4.6% of the world total. It is valuable to know whether the forestland supply can meet the demand of forest goods and services with the high growth rates of GDP and population annually in the future.

The long-term projections of forest product consumption have significant practical relevance as they are likely to influence government policymaking and forest management decision making (Hetemäki & Obersteiner 2001). Sedjo et al (1995) predicted that wood supply and demand would increase at nearly comparable rates. Apsey and Reed (1995) predicted that wood

demand would exceed its availability on a global scale by a “hypothetical gap” of some 400 million m<sup>3</sup> in 2010, and nearly 600 million m<sup>3</sup> in 2020. Nilsson (1996) had a situation whereby potential wood demand would exceed supply by nearly 800 million m<sup>3</sup> in 2010 and nearly 900 million m<sup>3</sup> in 2020. Solberg et al (1995) suggested that the world's forests are capable of providing industrial wood consistent with consumption projections of the future. Most of the projections of future adequacy of wood supply fell within the same orders of magnitude, but a few projected major supply gaps. Consensus appears to be tending towards a “non-crisis” future situation (FAO 1997).

In the light of social-economic developments, forest services other than timber production have gained international importance and recognition (Janse and Ottitsch 2005). Because forest ecosystems provide more important services, such as watershed protection, biodiversity conservation, carbon sequestration and microclimate regulation, forest ecosystems is one of the most important life-support ecosystems on earth (Subhrendu and Butry 2003). Increasingly, all these services are attracting more attention from the industry and government, as well as private citizens (Daily 1997; Costanza et al. 1997). In the same way, forest ecosystem services have already become a hot topic in China, and many forestry officials and scholars are paying more attention to them (Li and Zhao 2004). It seems that the concept of forest ecosystem services can help China for forestry sustainable development.

Although forest ecosystem services are receiving increasing attention, it is very difficult to value and quantify them. Consequently, some argued that the valuation of ecosystem is either impossible or unwise, because we cannot place a value on such

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“intangibles” as human life, environmental aesthetics, or long-term ecological benefits. However, we do not have a choice. The value of ecosystem services must be estimated for forest management. In this study, we attempt to project forestland resources in terms of forest ecosystem goods and services for the first half of 21st century in China.

## Methodology

### Main assumptions

In this study, the base assumptions include some essential factors affecting the demand and supply of forestland, such as population changes, social-economy development targets, forest management methods and forestland productivity, etc. The general principles were listed as follows: (1) The growth of human population is the determinant driving factor of forest products consumption; (2) The higher target of social-economic development will facilitate the higher level of consumption per capita of forest goods and services; (3) The policy of Classified Forest Management (CFM) will be strictly implemented in China in the future, and ecological-forest oriented for ecological services, commercial-forest oriented for forest goods; (4) Improving technology of forest management can increase directly the forestland productivity, and then save forestland acreage demanded.

### Population model

Many projections suggested that the future human populations will place even more pressure on forest resources, so that a critical consideration on the demand for forest products should be human population growth (Youngquist and Hamilton 2000). Furthermore, Rees (1990) stated that the corresponding human population is a function of per capita rates of material consumption, expressed by the following formula (Jansson et al. 1994):

$$(\text{Total human impact on the ecosphere}) = (\text{Population}) \times (\text{Per capita impact}) \quad (1)$$

In this study, we assume that population was the main driving factor on the forest ecosystem goods and services. As for the data of population, we referred to the existing population model developed by research group from Chinese Academy of Science, focused on China's sustainable development. This population model is based on the steady age structure and change, so it is suitable for the purpose of predicting natural resources (Yan et al. 2006).

### Social and economic development model

China has presented a goal of building a ‘Well-off Society’, which places emphasis on equity and various concerns related to the quality of life. In the first step, China's GDP will quadruple between the years of 2000 and 2020, where the per capita GDP in 2020 would reach about 3 500 USD. That means Chinese economy needs to grow at an average annual rate of 7.2% until

2020 (Zhu 2004). In succession, China wants to come up with the life standards of average developed countries by the year 2050.

Predictions of China's population, economy and society in the 21st century were achieved in our previous research listed in Table 1 (Yan et al. 2006). We used these data as the foundation and background for prediction of forestland in this study.

**Table 1. Prediction of China's population, economy and society during the years of 2000–2050**

Item	Unit	Year					
		2000	2010	2020	2030	2040	2050
Population	Total (10 <sup>9</sup> person)	1.27	1.37	1.46	1.51	1.54	1.53
Society	Urbanization Level (%)	36.2	46.0	55.0	62.0	69.0	75.0
Economy	GDP per capita (US\$, 2000 price)	842	2400	3200	5900	7200	11400

The demand for timber products in China was increasing in the late 1990's, and is likely to continue to increase in the future. Lang and Chan (2005) thought that there are two main reasons: (1) economic development and related increases in housing construction; and (2) reductions in tariffs and changes in regulations on importing of forest products, related to accession to the WTO. For example, the government intended to increase the living space in urban areas from 8.7 m<sup>2</sup> per person in 1997 to 10 m<sup>2</sup> per person in 2003, with an expected further increase to 13 m<sup>2</sup> per person by the year 2010. Moreover, the improving standard of living also raises the demand for interior decorations and furniture.

Generally, the rate of forest cover is a useful index to represent social welfare. For example, the research group from National Bureau of Statistics of China has declared that the status of Well-off Society could be measured by 16 indices, including 15% of forest cover (Zhu and Wu 2003).

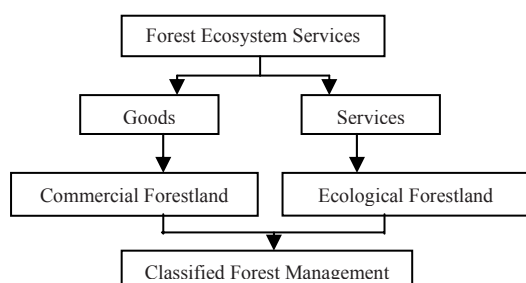
### Forest management method

Classified Forest Management (CFM) seems to be an acceptable approach for managing forests in China. On the one hand, ecological-forest, including primary, secondary, and shelter forests, provides main non-wood forest products and unique ecological services. On the other hand, commercial-forest, including timber and fuel forests, provides main timber or industrial raw woods. At the same time, ecological-forest were financed and provided by the government, while commercial-forest was cultivated by the private companies, which is helpful for Chinese forest sectors to achieve their forestry goals.

The goods and services of forest ecosystems correspond to timber production and ecological services from CFM (Fig. 1). Therefore, we assumed that forest ecosystem goods and services can come from commercial-forestland and ecological-forestland, respectively. In other words, the total forestland is the aggregate of the commercial and ecological forestland.

### Demand on forest ecosystem goods

With the development of national economy and improvement of people's living standard, the demands for forest products, especially for timbers, are continuously increasing. For example, the global timber production increased from 1.0 to 1.5 billion m<sup>3</sup> from 1961 to 1998, reflecting an annual growth rate of 1.8%. From 1996 to 2010, global industrial forest product production and consumption are projected to increase at a rate of 1.7% per year (FAO 1999). Between 1961 and 1998, consumption growth averaged 3.2% per year in developing countries and only 0.6% per year in developed countries (Bazett 2000). Table 2 lists the predicted growth rates of timber consumption of Asia, World and China provided by expert organizations such as FAO and ITTO (FAO 1997; ITTO 1999). The average growth rate of timber consumption was approximately 2.55% from 1970 to 2010.



**Fig. 1** The relationship between classified forest management and forest ecosystem services

**Table 2.** Growth rate of timber consumption from 1970 to 2010

Region	Production	Past annual growth rate (%)	Predicted annual growth rate (%)
Asia	Total Round Wood	1.91(1970-1990)	1.15(1996-2010)
	Paper and board products	5.84(1970-1990)	3.71(1996-2010)
World	Total Round Wood	1.73(1970-1990)	1.12(1996-2010)
	Paper and board products	3.16(1970-1990)	2.4(1996-2010)
China	Total Round Wood	2.6(1985-1997)	2(2000-2010)
	Paper and board products	0.95(1988-1996)	4.9(2000-2010)

Sources: State of the world's forests, 1997; State of the world's forests, 1999; ITTO 19

As we know, the consumption per capita of forest production must be influenced by economic models, living standards and life styles. It was very difficult to forecast them, but we can infer it through the data from developed countries. Nowadays, the annual average per capita consumption of timber is 0.58 m<sup>3</sup> over the world, 1 m<sup>3</sup> in developed countries, and 0.48 m<sup>3</sup> in developing countries (FAO 1997). Shi et al (1998) stated that timber demand in China will be on an increase in the coming 15 years or even longer period. With a view to economic development,

housing construction, accession to the WTO, ITTO projected the annual growth rate of timber consumption in the future will be 2% in China, increasing by 0.0058 m<sup>3</sup> per capita every year (ITTO 1999).

### Demand on forest ecological services

There are many factors to influence the function of forest ecosystem, such as biodiversity, forest stand structure and age, and so on, but those data are difficulty to collect and utilize. Fortunately, forest cover area and stock volume can indicate the general trends about the capability of forest ecosystem services. For example, natural forest stand with a large stock volume has higher forest ecosystem function, vice versa. This experience was validated by forest stand both in Hainan island in south of China, and Changbai mountain in Northeast of China (Li et al. 2002). Table 3 illuminates this relationship between the growing stocks with capacity of ecosystem services.

**Table 3.** The relationship between the growing stocks with capacity of ecosystem services

Type	Growing stock (m <sup>3</sup> ·ha <sup>-1</sup> )	Capacity of Ecosystem services	EFE
Young forest	24.8	Minimum	0.248
Middle age forest	73.6	Lower	0.736
Nearly matured forest	110.4	Middle	1.104
Mature forest	173.7	High	1.737
Over matured forest	266.5	Maximum	2.665

Above all, we hypothesize that one hectare natural forestland with 100 m<sup>3</sup> stock volume can provide one unit ecological services, named ecological forestland equivalent (EFE). It was reference unit for the ecological function evaluation of various forest ecosystems. Thus, one hectare of natural forestland with 150 m<sup>3</sup> stock volume is corresponds to 1.5 units of EFE; in the same way, one hectare with 50 m<sup>3</sup> is 0.5 units EFE. Previous research testified that artificial forest has lower forest ecosystem services than natural forest, only 70% of the latter (Li et al. 2002). Hence, we assume that one hectare plantation with 100 m<sup>3</sup> stock volume was equal to 0.7 units EFE, and the coefficient of plantation's EFE  $\lambda$  is 0.7.

Because China wants to come up with the life standards of average developed countries by the year 2050, this paper assume that China will have the same level of consumption forest services with some developed countries. In Table 4, one group of developed countries, which have a good ecological and environmental situation, was listed for comparison, and fixed on those country's per capita EFE as China's target by the year 2050 (Research Group on the Strategy for Modernization in China and the China Center for Modernization Research 2004). Calculating by the concept of EFE, the average per capita EFE of those developed countries was approximately 0.6 units by the year 2000, and China is only 0.1 units. Thus, we assume that per capita EFE of Chinese will increase by 1% annually, from 0.1 units EFE by 2000 to 0.6 units EFE by the year 2050.

### Forestland productivity

The pressure being placed on the resource also pushes technological developments to help divert those pressures (Youngquist and Hamilton 2000). Since the Chinese government holds the theory that the scientific and technological development is productivity, Chinese forest sectors pay more attention to forest science research and put the research achievements into practice. They believe that a high commercialization rate of forest research findings is the main driving factor affecting forestland productivity.

**Table 4.** Per capita EFE of one group developed countries.

Countries	Ecological Forest area (10 <sup>6</sup> ha)	Population (10 <sup>6</sup> Person)	Stumpage Volumes (m <sup>3</sup> ·ha <sup>-1</sup> )	Per capita Eco-forest Index
Japan	24.2	124.0	118	0.2
Germany	10.5	79.1	266	0.3
Australia	39.8	17.1	83	1.6
France	13.1	56.6	136	0.3
New Zealand	7.5	3.4	53	1.2
Korea, Rep	6.3	43.3	73	0.1
Average				0.6

In this study, we assume that the commercialization rate of forest research findings is the growth rate of forestland productivity in the future. Thus, forestland productivity can be calculated by the following equation:

$$P_i = (1 + R_i) \times P \quad (2)$$

where  $P_i$  is the forestland productivity in  $i$  year,  $R_i$  the commercialization rate of forest research findings in  $i$  year, and  $P$  is the initialization of forestland productivity in base-year 2000.

The SFA forecasted that the commercialization rate of forest research findings will be 45%, 50%, and 60% during three stages 2000–2010, 2010–2020, and 2020–2050 respectively (Research Group on the Strategy for Sustainable Forestry Development of China 2003). Based on Eq. 2, commercial-forestland productivity will increase from 34.8 to 50.4, 75.5 and 120.8 m<sup>3</sup>·ha<sup>-1</sup> and the ecological-forestland productivity will increase from 78.0 to 113.2, 169.7 and 254.6 m<sup>3</sup>·ha<sup>-1</sup>, during the three stages 2000–2010, 2010–2020, and 2020–2050, respectively (Table 5).

Above all, the total forestland is the aggregate of timber forestland and ecological forestland. It can be calculated by the following equation:

$$\text{Total forestland} = \text{population} \times (\text{per capita timber forestland} + \text{per capita ecological forestland}) \quad (3)$$

or

$$V_t = P_t \left( \frac{W_{t_0}(1+\alpha)^{\frac{t-t_0}{T}}}{A_{t_0}(1+m_1)(1+m_2)\cdots(1+m_j)} + (1-\lambda) \frac{E_{t_0}(1+\beta)^{\frac{t-t_0}{T}}}{B_{t_0}(1+n_1)(1+n_2)\cdots(1+n_k)} \right) \quad (4)$$

where  $V_t$  is the total forestland area in  $t$  year,  $P_t$  the population in  $t$  year,  $t$  the year,  $W_{t_0}$  the initialization of per capita timber,  $E_{t_0}$  the initialization of per capita consumption of ecological forestland,  $\alpha$  the growth rate of timber consumption,  $\beta$  the growth rate of ecological-forestland consumption,  $A_{t_0}$  the initialization of commercial-forestland productivity, and  $B_{t_0}$  is the initialization of ecological-forestland productivity. On the assumption that there are  $j$  phases during  $t-t_0$ , the  $m_1, m_2 \dots m_j$  is the growth rate of commercial-forestland productivity each phases, respectively,  $n$  is the growth rate of ecological-forestland productivity each phases, and  $\lambda$  is the coefficient of plantation's EFE.

**Table 5.** The projected forestland productivity in three stages.

Stage (i)	Foresight period	Commercialization rate of research findings (%)	Commercial forestland Productivity (m <sup>3</sup> ·ha <sup>-1</sup> )	Ecological forestland Productivity (m <sup>3</sup> ·ha <sup>-1</sup> )
1	2000–2010	45	50.4	113.2
2	2010–2020	50	75.5	169.7
3	2020–2050	60	120.8	254.6

## Results

### Demand difference of commercial and ecological forestland

The result of the prediction based on our models was listed in Table 6. According to the result, the total demand of forestland will continually increase in China within the first half of 21 century. However, there are remarkable differences between commercial and ecological forestland. On the one hand, commercial-forestland demand will increase sharply with the growth of population and timber consumption. Total annual timber consumption volumes will double current levels by the year 2035 and increase to 880 million m<sup>3</sup> by the year 2050, twelve times of that in 2005. After 2020 the area of commercial-forestland should be stabilized to 7.6 million ha, 0.8% of the total territory and 2% of the total forest area. On the other hand, ecological-forestland demand will increase from 15.5 million ha in 2000 to 35.5 million ha by the year 2050, double within 50 years. Thus, ecological-forestland will be 37.1% of the total territory.

### Relationship between population and forestland

Fig. 2 demonstrates the comparing population growth with demand on total forestland resources until 2050. The demand on forestland will increase synchronously with the population variable by 2050, but the growth rate of forestland demand is quicker than population growth rate. Although population will decrease after 2040's, the demand of forestland will increase continuously.

## Discussion

### Demand trends of forestland

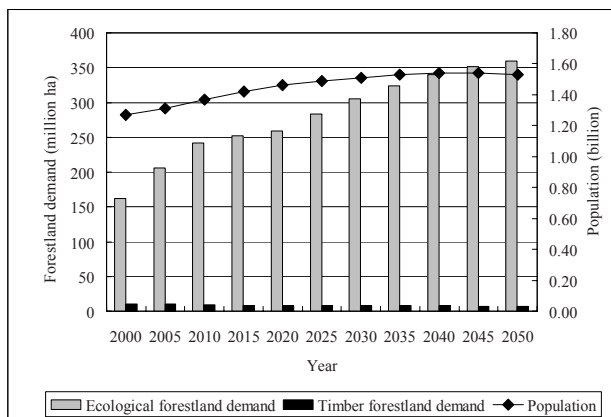
It is obvious that the China's market will experience an overall increasing trend in consumption of forestland in the future. From

2005 to 2050, the total forestland needs to increase from 165.5 million ha to 362.2 million ha, covering 37.86% of China's ter-

ritory in area. It requires than the area of forestland increases by 3.9 million ha annually.

**Table 6. Prediction of forestland demand during the years of 2000 to 2050 in China.**

Year	Population (10 <sup>9</sup> person)	Demand of Per-capita timber (m <sup>3</sup> )	Timber Demand (10 <sup>6</sup> m <sup>3</sup> )	Growing Stock of timberland (m <sup>3</sup> ·ha <sup>-1</sup> )	Timberland (10 <sup>6</sup> ha)	EFE	Growing stock of eco-forestland (m <sup>3</sup> ·ha <sup>-1</sup> )	Ecological forestland (10 <sup>6</sup> ha)	Total Forestland (10 <sup>6</sup> ha)	Forest coverage (%)
2000	1.27	0.29	367.6	34.76	10.6	0.10	78.1	155.0	165.5	17.30
2005	1.31	0.32	419.4	42.56	9.9	0.15	95.6	199.3	209.2	21.87
2010	1.37	0.35	476.6	50.36	9.5	0.20	113.2	235.3	244.8	25.59
2015	1.42	0.38	536.5	62.95	8.5	0.25	141.4	245.6	254.1	26.56
2020	1.46	0.41	594.4	75.54	7.9	0.30	169.7	253.3	261.2	27.30
2025	1.49	0.44	648.1	83.09	7.8	0.35	183.8	278.2	286.0	29.90
2030	1.51	0.46	700.1	90.64	7.7	0.40	198.0	299.4	307.2	32.11
2035	1.53	0.49	752.3	98.19	7.7	0.45	212.1	318.3	326.0	34.08
2040	1.54	0.52	802.4	105.74	7.6	0.50	226.3	334.3	341.9	35.74
2045	1.54	0.55	847.1	113.29	7.5	0.55	240.4	346.4	353.9	36.99
2050	1.53	0.58	886.1	120.84	7.3	0.60	254.6	354.9	362.2	37.86



**Fig. 2 Comparison of population growth with the demands of ecological forestland and commercial forestland until 2050.**

However, some significant differences exist between commercial-forestland and ecological-forestland. First, the area of commercial-forestlands must reach 7.6 million ha by the year 2020 to meet the growing demand, and 7.3 million ha by the year 2050 with the higher forestland productivity. In other words, China can meet the demand for timber with 7.3 million ha of high quality timberland, whose average growing stock must be over 120.8 m<sup>3</sup>·ha<sup>-1</sup>. Nowadays, the Chinese government is making more efforts to enhance the productivity of plantations, which is a pragmatic strategy. In fact, Commodity forest plantations play a very important role in China because they will complement and reduce pressures on existing natural forests.

Furthermore, there will be tremendous demand on ecological-forestland, larger than on commercial-forestland. It will continuously increase until 2050 by a 1% annual growth rate. One important reason is that this study set a high goal to catch up the same levels as some developed countries. Meanwhile, the study predicts that it will be very difficult to meet ecological-forestland demand, even if the forestland productivity reaches a maximum of stock volume per capita. Apparently, the supply and demand of ecological forest will be the main concern for China in the future.

#### Gap between goal established and our projection

Our analyses also illustrate that the afforestation goal established by SFA is deficient for meeting the demands of a Well-off Society by the year 2050. In 2003, SFA declared their development goals:

By the year 2010, national forest coverage will reach 20.3%; 22 million ha of land affected by desertification will be converted to forests and grasslands; 30% of urban areas will be covered by trees and grass in 70% of cities.

By the year 2020, national forest coverage will reach 23.5%; 20 million more ha of land affected by desertification will be converted to forests and grasslands; 35% of urban areas will be covered by trees and grass in 70% of cities.

By the year 2050, national forest coverage will reach 28%; all land affected by desertification deemed suited to plant tree will be converted to forests and grasslands; 45% of urban areas will be covered by trees and grass in 70% of cities.

Comparing with our projection, China will potentially face a supply shortage of forestland supply (Table 7). For example, forestland demand needs to be 28% by the year 2020, which can be achieved by the year 2050. By the year 2050, the demand must be 37.86%, only 28% available, the gap is 9.9%. Moreover, China has no room to plant trees due to the shortage of land at that time.

**Table 7. Comparison of predicted demands with established goals for forest coverage and forest area**

Time	Established goals		Predicted demands		Gap (10 <sup>6</sup> ha)
	Forest coverage (%)	Forest area (10 <sup>6</sup> ha)	Forest coverage (%)	Forest area (10 <sup>6</sup> ha)	
2000	16.3	156.48	18.1	172.94	16.46
2010	20.3	181.77	26.28	182.46	0.69
2020	23.5	220.04	27.88	251.43	31.39
2050	28	249.67	38.4	367.38	117.71

## Enhancing the forest ecosystem function

More forest ecosystem goods and services are needed than were previously expected due to the large population and the relatively high standard of living required in the first half of 21st century. The Chinese forest sector needs to take steps more highly effective than previously implemented methods, such as protecting natural forests as soon as possible, enriching the biodiversity of plantations, preventing the spread of invasive species, and so on.

We think that several ongoing key projects concerning forestry development, such as National Forest Conservation Programme (NFCP), reclaiming farmland for forestland and grassland etc, should pay more attention to forest ecosystem functions (Zhang et al. 2000). It is fruitless to solely pursue the plantation area, the survival rate, and the invasive species. Thus, we suggest that the forest sector ought to enlarge the forestland area (especially ecological forest area), improve the forestland utilization efficiency, clarify the tenure of forest, and to take full advantage of barren land and hills for planting forests during the years of 2000 to 2010. Furthermore, to adjust forest construction is a good countermeasure for dealing with the large gap of forestland area, such as increasing the area of protective forest. In addition, scientific research and international forestry cooperation need to be strengthened.

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